entrance pupil points of interest. These are chosen to be the edge of each space, so that these rays produce the bounding volume for the beam. The x and y global coordinate data is collected on the surface planes of interest, typically an image of the field and entrance pupil internal of the optical system. This x and y coordinate data is then evaluated using a convex hull algorithm, which removes any internal points, which are unnecessary to produce the bounding volume of interest. At this point, tolerances can be applied to expand the size of either the field or aperture, depending on the allocations. Once this minimum set of coordinates on the pupil and field is obtained, a new set of rays is generated between the field plane and aperture plane (or vice-versa).

These rays are then evaluated at planes between the aperture and field, at a desired number of steps perceived necessary to build up the bounding volume or cone shape. At each plane, the ray coordinates are again evaluated using the convex hull algorithm to reduce the data to a minimal set. When all of the coordinates of interest are obtained for every plane of the propagation, the data is formatted into an *xyz* file suitable for FRED optical analysis software to import and create a STEP file of the data. This results in a spiral-like structure that is easily imported by mechanical CAD users who can then use an automated algorithm to wrap a skin around it and create a solid that represents the beam.

This work was done by Joseph Howard and Lenward Seals of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16176-1

High-Performance, Multi-Node File Copies and Checksums for Clustered File Systems

Ames Research Center, Moffett Field, California

Modern parallel file systems achieve high performance using a variety of techniques, such as striping files across multiple disks to increase aggregate I/O bandwidth and spreading disks across multiple servers to increase aggregate interconnect bandwidth. To achieve peak performance from such systems, it is typically necessary to utilize multiple concurrent readers/writers from multiple systems to overcome various single-system limitations, such as number of processors and network bandwidth. The standard cp and md5sum tools of GNU coreutils found on every modern Unix/Linux system, however, utilize a single execution thread on a single CPU core of a single system, and hence cannot take full advantage of the increased performance of clustered file systems.

Mcp and msum are drop-in replacements for the standard cp and md5sum programs that utilize multiple types of parallelism and other optimizations to achieve maximum copy and checksum performance on clustered file systems. Multi-threading is used to ensure that nodes are kept as busy as possible. Read/write parallelism allows individual operations of a single copy to be overlapped using asynchronous I/O. Multi-node cooperation allows different nodes to take part in the same copy/checksum. Split-file processing allows multiple threads to operate concurrently on the same file. Finally, hash trees allow inherently serial checksums to be performed in parallel.

Mcp and msum provide significant performance improvements over standard cp and md5sum using multiple types of parallelism and other optimizations. The total speed-ups from all improvements are significant. Mcp improves cp performance over 27×, msum improves md5sum performance almost 19×, and the combination of mcp and msum improves verified copies via cp and md5sum by almost 22×. These improvements come in the form of drop-in replacements for cp and md5sum, so are easily used and are available for download as open source software at http://mutil.sourceforge.net.

This work was done by Paul Z. Kolano and Robert B. Ciotti of Ames Research Center. Further information is contained in a TSP (see page 1). ARC-16494-1

Stiffness and Damping Coefficient Estimation of Compliant Surface Gas Bearings for Oil-Free Turbomachinery

Initial applications include design of turbochargers, blowers, compressors, pumps, and turbine engines.

John H. Glenn Research Center, Cleveland, Ohio

Foil gas bearings are a key technology in many commercial and emerging oil-free turbomachinery systems. These bearings are nonlinear and have been difficult to analytically model in terms of performance characteristics such as load capacity, power loss, stiffness, and damping. Previous investigations led to an empirically derived method to estimate load capacity. This method has been a valuable tool in system development. The current work extends this tool concept to include rules for stiffness and damping coefficient estimation. It is expected that these rules will further accelerate the development and deployment of advanced oil-free machines operating on foil gas bearings.

Foil gas bearings are self-acting hydrodynamic bearings comprised of a series of sheet-metal foil layers from which they derive their name. They are compliant bearings that offer high-speed rotor support while accommodating shaft misalignment and distortion often encountered in turbomachinery. Lightly loaded, low-temperature foil gas bearings are commodities that predominate in the rotor support for aircraft air cycle machines (ACMs). More highly loaded foil bearings operating at high temperatures are an emerging technology making commercial inroads into several markets including aircraft auxiliary power units (APUs), microturbines, gas compressors and blowers, and turbochargers.

The general trend for foil bearings since their initial development over five decades ago is application to larger and more complex rotor systems. As this proliferation occurs, more practitioners will become actively involved with new machine development using foil bearings. Thus, there is a great need for application guidelines to establish the feasibility of proposed rotor systems and to identify existing machines that are good candidates for foil bearing use. Specifically, a method is needed to estimate foil bearing stiffness and damping behavior in order to foster advanced oil-free rotating machine development.

Methods to estimate critical stiffness and damping parameters, however, do not currently exist. The purpose of the methods put forth in this work is to establish simple tools capable of estimating foil bearing stiffness and damping coefficients suitable for oil-free rotor support design work. This has been accomplished by first coalescing all available empirical data on foil bearing performance that has been generated in the author's own laboratories, and by researchers working in university, government, and industrial laboratories. This information is examined and combined, then used to develop ROT for foil bearing stiffness and damping. These ROTs can then be combined with existing rules for load capacity to obtain credible feasibility assessments for proposed oil-free rotor systems.

The effort described has resulted in algebraic models for foil gas bearings that yield stiffness, damping, and load capacity values as a function of bearing size, design, and operating speed. With these models, one can easily determine the feasibility of building a foil bearing supported machine without incurring the expense of early experimental work. The models presented represent the only known and verified methods to predict conveniently foil bearing performance properties.

This work was done by Christopher DellaCorte of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18755-1.

Sampling and Reconstruction of the Pupil and Electric Field for Phase Retrieval

Goddard Space Flight Center, Greenbelt, Maryland

This technology is based on sampling considerations for a band-limited function, which has application to optical estimation generally, and to phase retrieval specifically. The analysis begins with the observation that the Fourier transform of an optical aperture function (pupil) can be implemented with minimal aliasing for Q values down to $Q = 1$. The sampling ratio, Q, is defined as the ratio of the sampling frequency to the band-limited cut-off frequency. The analytical results are given using a 1-d aperture function, and with the electric field defined by the band-limited sinc(x) function. Perfect reconstruction of the Fourier transform (electric field) is derived using the Whittaker-Shannon sampling theorem for $1<Q<2$.

The Fourier transform is constructed by periodic extension, i.e., by spacing copies of the transform in a definite way, recognizing that no aliasing occurs for values of the sampling ratio such that $1<Q<2$, which can be used to advantage in the application of phase retrieval estimation. A method was developed for propagating the electromagnetic field with no aliasing, which has been extended to 2-d optical apertures.

This work was done by Bruce Dean, Jeffrey Smith, and David Aronstein of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15947-1

Space Operations Learning Center Facebook Application

This app uses the latest networking technology to inspire young audiences to be interested in math, science, and engineering.

Goddard Space Flight Center, Greenbelt, Maryland

The proposed Space Operations Learning Center (SOLC) Facebook module, initially code-named "Spaceville," is intended to be an educational online game utilizing the latest social networking technology to reach a broad audience base and inspire young audiences to be interested in math, science, and engineering.

Spaceville will be a Facebook application/game with the goal of combining learning with a fun game and social environment. The mission of the game is to build a scientific outpost on the Moon or Mars and expand the colony. Game activities include collecting resources, trading resources, completing simple science experiments, and building architectures such as laboratories, habitats, greenhouses, machine shops, etc. The player is awarded with points and achievement levels. The player's ability increases as his/her points and levels increase. A player can interact with other players using multiplayer Facebook functionality. As a result, a player can discover unexpected treasures through scientific missions, engineering, and working with others.

The player creates his/her own avatar with his/her selection of its unique appearance, and names the character. The player controls the avatar to perform activities such as collecting oxygen mole-